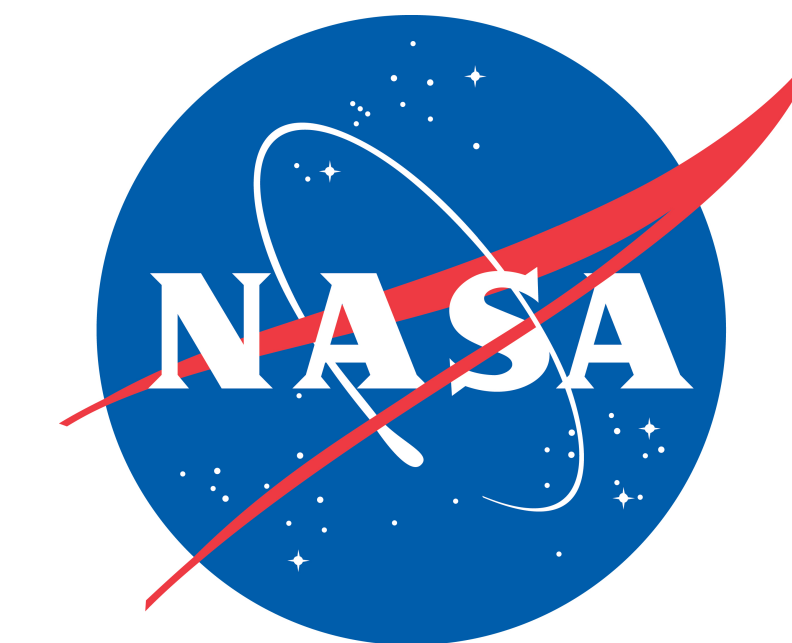




Hemispherical Optical Dome for Underwater Communication

Ron S. Shiri, Emily L. Lunde, Patrick L. Coronado, and Manuel A. Quijada 'Presenter'
NASA / Goddard Space Flight Center



INTRODUCTION

NASA is developing technology that could enable autonomous underwater drones, studying Earth's oceans and those on icy moons like Jupiter's Europa, to transmit a large volume of image and video data to a receiver at the surface via optical wireless communications. Such an optical system requires a wide field-of-view in order for a moving transmitter to be detected by a stationary receiver (Figure 1). For this purpose, we have designed, developed, and tested an optical hemispherical dome, employing multiple focusing lenses and housing an array of photodiodes at the focal plane. This design achieves a wider optical field-of-view for the underwater communication system.

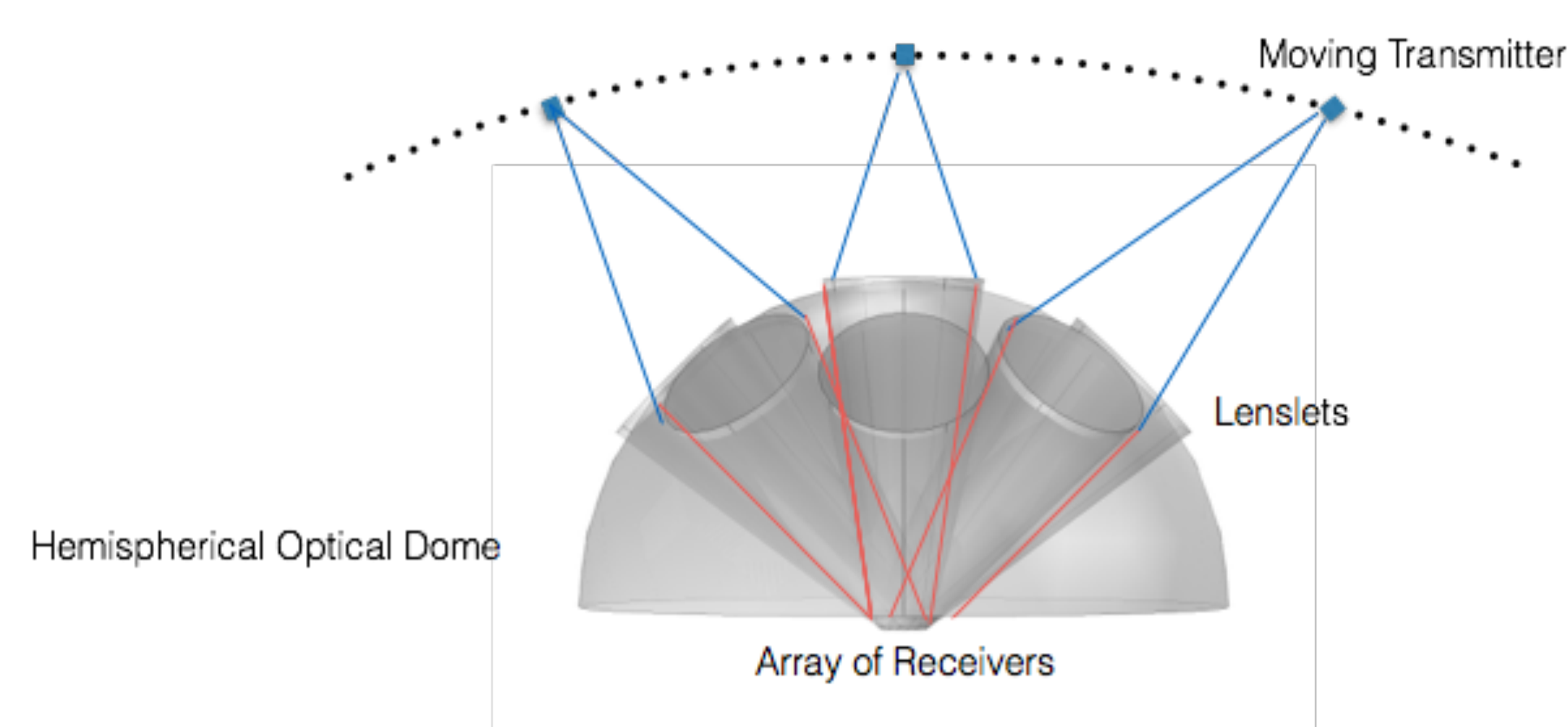


Fig. 1. Hemispherical Optical Dome (HOD) for underwater optical wireless communication

A light beam/pulse propagating through aquatic media suffers from attenuation and spreading in the spatial, angular, temporal and polarization domains. The attenuation and spreading are wavelength dependent and result from absorption and multiple scattering of light by water molecules and by marine hydrosols (mineral and organic matter). Figure 2 shows blue and green wavelength are least attenuated by water.

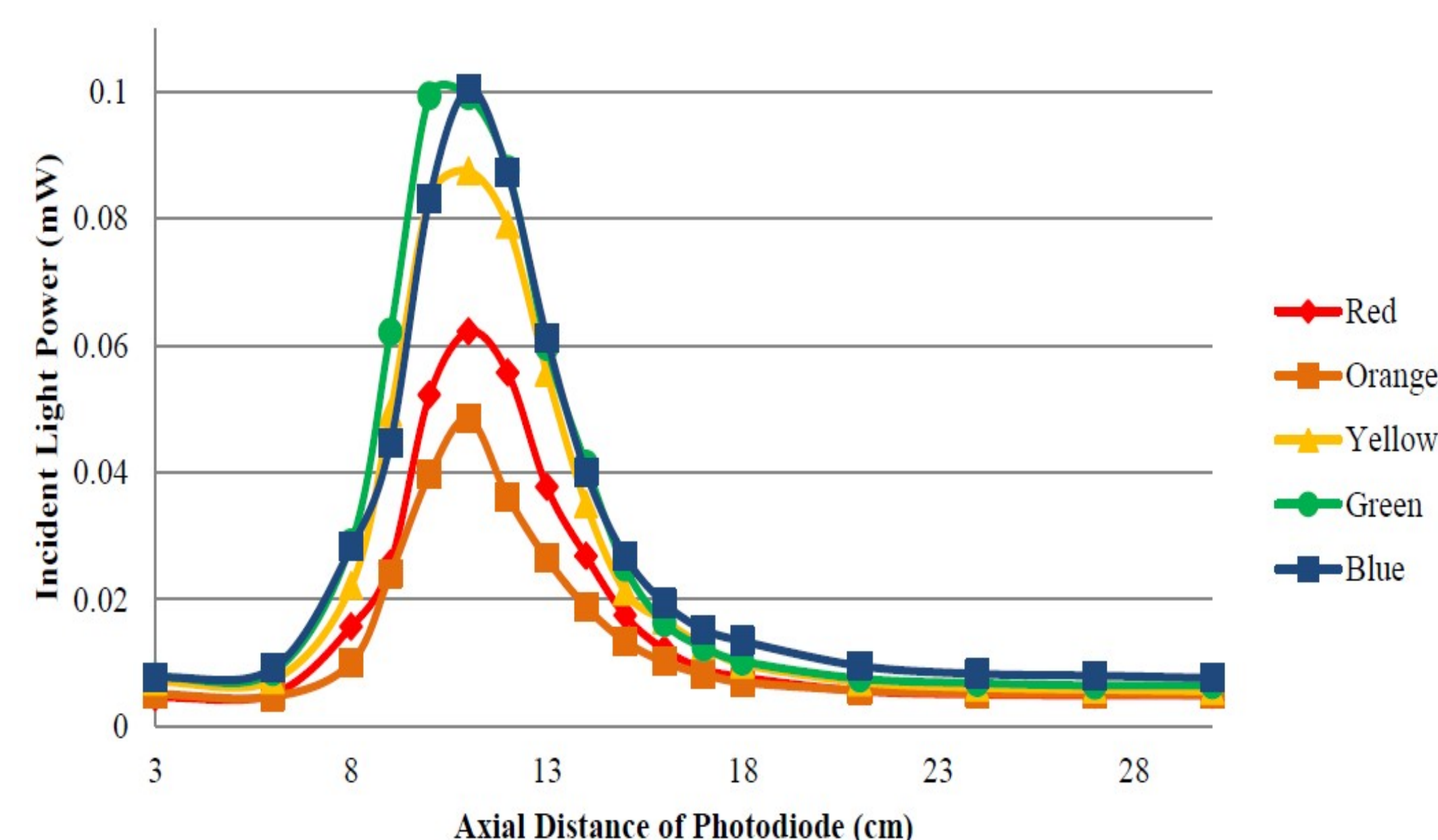


Fig. 2. Incident light power is dependent on wavelength

As light travels through the water, it is attenuated (loses intensity) due to absorption and scattering, together referred to as extinction. The rate of decrease in light intensity can be described using an extinction coefficient. The extinction coefficient is greater for a murkier water due to higher levels of hydrosols.

METHODS

The dome structure was designed using PTC's Creo CAD software and then a prototype was built with a 6-inch diameter transparent camera dome. Holes were cut in the camera dome using a 5-axis mill cut holes and were retrofitted with 2-inch diameter lenses (Figure 3).



Fig. 3. CAD model of dome

The lens configuration has been modeled using Synopsys' CODE V optical design software. Each lens has a focal length of 75 mm and clear aperture of 50.8 mm. The model was used to optimize the LED position in the focal plane with respect to dome at a distance of 300 mm (Figure 4).

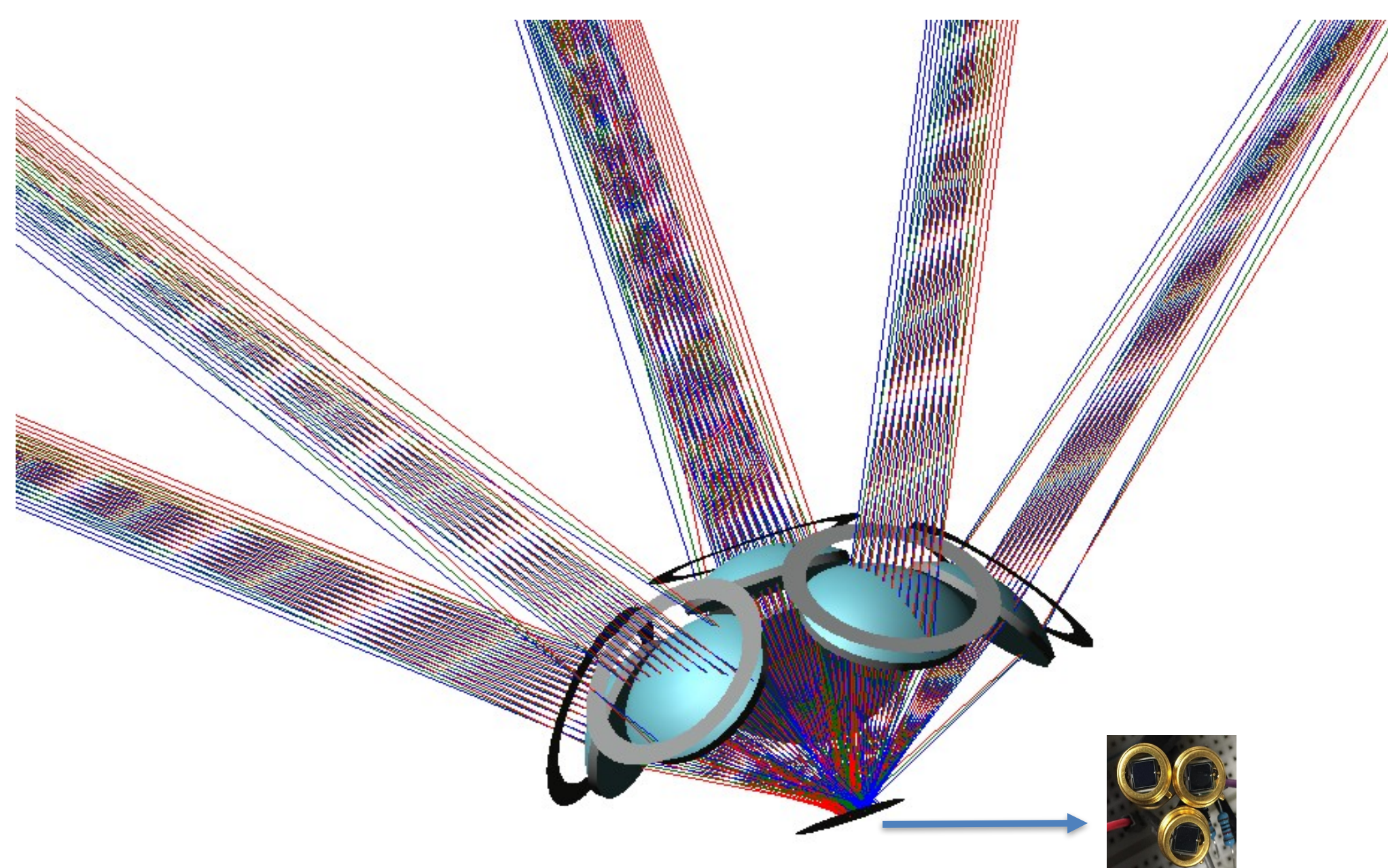


Fig. 4. Code-V optical model of dome and lenses plus photodiode configuration at the base of the dome

We employed multiple photodiodes to increase the portion of the field of view from which transmitted light from the LED sources can be detected. This work shows that the dome design improves the optical field of view of the underwater communication system considerably. Furthermore, with the experimental test results, a geometric optimization model was developed, providing insights to the design performance limits.

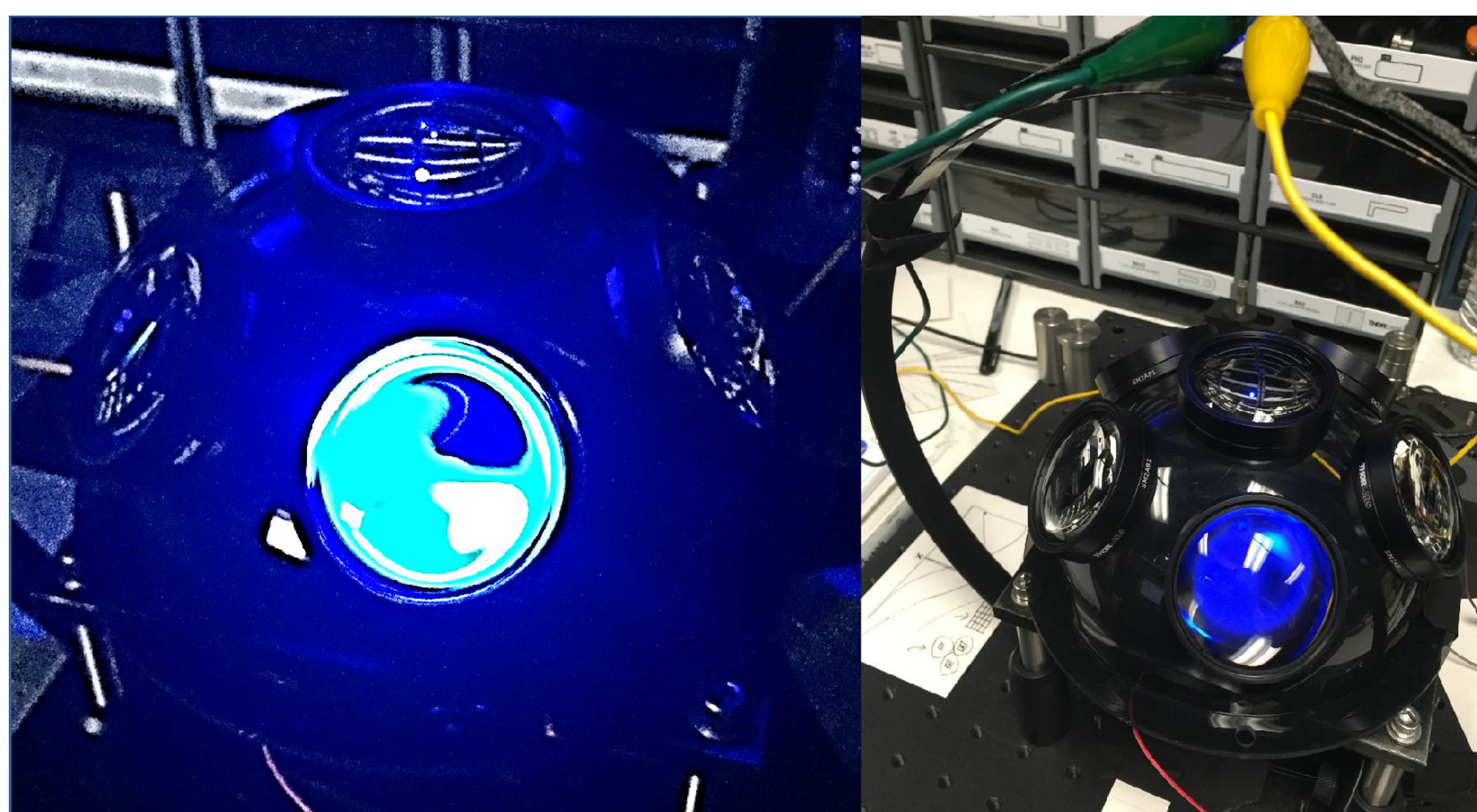


Fig. 5. Hemispherical dome being tested

RESULTS

Underwater optical communication follows a general line-of-sight communication, assuming a straight and unobstructed path of communication between the transmitter and receiver. The power reaching receiver is obtained from

$$P_{R_LOS} = P_T \eta_T \eta_R L_{pr} \left(\frac{\lambda d}{\cos(\theta)} \right) \left(\frac{A_{Rec} \cos(\theta)}{2\pi d^2 (1 - \cos(\theta_0))} \right)$$

Where P_T is average transmitted optical power, η_T is the optical efficiency of the transmitter, η_R is the optical efficiency of the receiver, d is perpendicular distance between transmitter and receiver, θ is the angle between the perpendicular to the receiver plane and transmitter – receiver trajectory, θ_0 is beam divergence angle, and A_{Rec} is receiver aperture area. Figure 6 shows the power recorded at the receiver (photodiode) under different scenarios. The red line shows power received by 3 photodiodes with wide field of view.

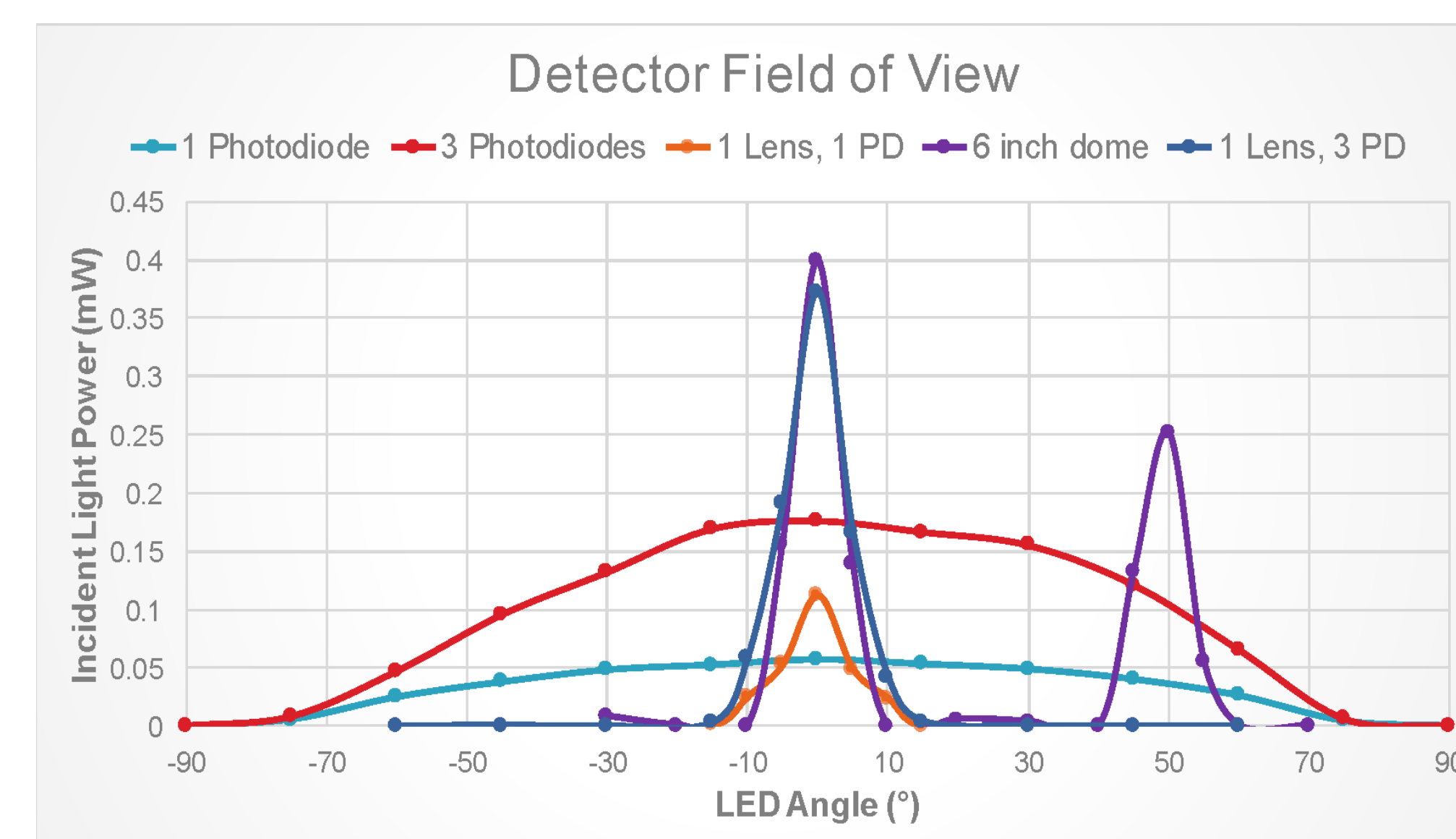


Fig. 6. Field of view of 5 different detector systems

CONCLUSIONS

An optical dome for underwater optical wireless communication was designed and tested, that contains 6 lenses for the detection of light from a moving transmitter by 3 photodiodes positioned at the focal plane of the lenses. In this design, we achieved an increased power at the detector while widening the field of view. This is important since the dome allows the photodiodes to detect the light when the source is located off of the optical axis. The performance of the system could be improved by increasing the number of lenses on the dome and replacing the individual photodiodes with a planar array of photodiodes.

ACKNOWLEDGEMENTS

Special thanks to Matthew Showalter, John Wolfe, and Bo Kaufman for taking time to cut holes into the dome. Also, thanks to Laurie Seide and Garrett West for helping us to model optics in Code V.

REFERENCES

1. D. D. Gill, W. C. Sweatt, A. A. Claudet, V. C. Hodges, M. J. Vasile, and D. P. Adams, "Design and Manufacturing of Complex Optics: The Dragonfly Eye Optic", Sandia Report, SAND2007-0127, January 2007.